SCIAMACHY CLOUD PRODUCT VALIDATION

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ABSTRACT

The SCIAMACHY cloud products were validated by comparisons with lidar measurements and also with cloud products obtained using AATSR, MERIS, and MODIS. A good agreement between measurements performed by different instruments is found.

1. INTRODUCTION

The operational data processor for Scanning Imaging Absorption Spectrometer for Atmospheric CHartographY (SCIAMACHY) on board ENVISAT was subject to major revisions as described by von Bargen et al.(2006). In particular, the semianlytical cloud retrieval algorithm SACURA has been introduced in the operational retrieval scheme. The algorithm is based on asymptotic radiative transfer theory valid for thick clouds having optical thickness larger than five (Kokhanovsky et al., 2003). The cloud optical thickness (COT) and cloud spherical albedo are determined from the top-of-atmosphere (TOA) reflectance at the wavelength 758 nm and the cloud top height (CTH) is derived from the spectral TOA reflectance in the oxygen A-band centered at 760 nm. The physical background of the retrieval is based on the fact that the cloud reflectance outside gaseous and condensed matter absorption bands is determined almost exclusively by COT (with small influences due to the size of particles) and the cloud reflectance inside of gaseous bands depends in addition on CTH and also on the cloud geometrical thickness (CGT). CGT is assessed in the framework of the retrieval procedure. Further details of the algorithm are described by Rozanov and Kokhanovsky (2004). Applications of SACURA to the analysis of global data are presented by Kokhanovsky et al. (2005,2006).

The aim of this paper is to present our recent results with respect to the validation of CTH as derived by SACURA using lidar measurements and also comparisons of derived COT and CTH with other instruments such as MEdium Resolution Imaging Specrometer (MERIS), the Advanced Along Track Scanning Radiometer (AATSR) and Moderate Resolution Imaging Spectroradiometer (MODIS). AATSR, MERIS, and SCIAMACHY are on the same space platform (ENVISAT). MODIS is installed on TERRA, which flies 30 min behind ENVISAT.

2. THE VALIDATION OF THE SACURA-RETRIEVED CLOUD TOP HEIGHT USING LIDAR MEASUREMENTS

The validation flights with airborne lidar have been performed in the north-eastern part of Germany between April and June 2004. Flights were temporally and spatially synchronized with ENVISAT overpasses. The Cessna 207T of the Free University of Berlin was equipped with the portable lidar system POLIS of the University of Munich and a GPS navigation system. The maximum flying altitude was 3 km. The experiment was funded in the framework of the MERIS (Bezy et al., 2000; Fischer et al., 2000) validation activities (see, e.g., http://www.esa.int/envisat/instruments.html). However, results obtained are valuable also for other instruments on ENVISAT such as SCIAMACHY and AATSR.

The portable lidar system POLIS was developed and constructed for ground-based and airborne operations (Heese et al., 2002). POLIS data used in this study consists of measurements at 355 nm wavelength with 5 Hz pulse repetition frequency. Though the vertical resolution of the lidar data is 7.5 m we assume the overall accuracy of the determination of the cloud top height to be 30 m due to the limited accuracy (20 - 30 m) of the GPS on board the aircraft. This error is small as compared to an expected error of the oxygen A-band retrieval technique (Rozanov and Kokhanovsky, 2004). The lidar measurements suit very well for the purpose of comparisons with SCIAMACHY CTH results over extended cloud fields.

Yet a problem arises due to the different spatial scales of SCIAMACHY and lidar measurements. While

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SCIAMACHY measurements are an average of a two-dimensional 1800 km^2 area, the POLIS measurements form an one-dimensional trace of pinpoints with a diameter of typically two meters and a separation of 10 m. As it was mentioned above, POLIS measurements have been performed specifically for the validation of the MERIS CTH product (Lindstrot et al., 2006). Therefore, no special flight patterns inside larger SCIAMACHY ground scenes have been planned and performed. The analysis for flight patterns shows that aircraft measurements have been performed either in the vicinity of SCIAMACHY pixels or along one or two aircraft paths inside the pixel both for broken and overcast cloud cases. This means that meaningful comparisons are possible only after careful selection of the scene characterized by the cloud field positioned roughly at the same height for an extended area including the flight pattern and also SCIAMACHY large ground scene of 30*60 km^2.

The performed analysis using AATSR brightness temperature (see Fig.1) showed that such a condition occurred on May 12, 2004 (10:00UTC). The area of study was covered by an extended cloud field.

The cloud top altitude did not vary considerably at the day of measurements in the wide area related to this study (see Fig.1). This was concluded from the analysis of the cloud top during flights and also from simultaneous and independent measurements performed by AATSR and also the Spinning Enhanced Visible and Infrared Imager (SEVIRI) on board METEOSAT Second Generation (MSG) (see http://www.esa.int/msg/pag0.html). In particular, we have found that the standard deviation of SEVIRI cloud temperatures in the range of latitudes 52-53N, 12-13.5E, where satellite and lidar measurements have been performed, was smaller than 1 percent.

Therefore, the spatial/temporal mismatch of satellite and airborne measurements is of minor importance.

The retrieval of the cloud top height for the cloud field shown in Fig.1 using the operational SACURA version gives overestimation by 0.63 km for the case studied(2.33 km instead of 1.7 km as measured by POLIS).

This difference with the real cloud top height is of no importance for some applications (e.g., total ozone retrievals). However, the difference is larger as compared to MERIS retrievals for the same cloud system, which is around 0.2 km (Lindstrot et al., 2006).

One possibility to explain such a deviation is the calibration error of SCIAMACHY. To check this we have retrieved the cloud optical thickness at the wavelength 442 nm using vicarious calibration of SCIAMACHY. The well calibrated MERIS data at this wavelength have been used. It was found that SCIAMACHY Processor 5 data must be multiplied by 1.12 at 442 nm (Kokhanovsky et al., 2006).

This enables the determination of top-of-atmosphere reflectance values close to those of MERIS for a given scene. The details of the radiometric calibration procedure are given in Kokhanovsky et al. (2006). The value of the retrieved cloud optical thickness (COT) using recalibrated SCIAMACHY data was 36.6, which differs considerably from the value of the cloud optical thickness (24.0) obtained at the wavelength 758 nm using official Processor 5 SCIAMACHY data. Remind that the top-of-atmosphere reflectance is almost spectrally neutral for clouds. So the value of COT determined at 442 nm can be used also at 758nm. After the determination of a new COT we ran the retrieval algorithm and found that the estimation of cloud top height improved considerably (the error decreased from 0.63 to 0.18 km). This means that the use of the next generation Processor 6 SCIAMACHY data scheduled for 2007 will improve the SACURA CTH retrieval accuracy considerably.

We conclude that oxygen A-band spectrometry for low clouds enables the determination of the altitude of low clouds with a high precision. Importantly, no look-up-tables (LUTs) are used in the retrieval processes. LUTs are quite large in this case taking into account the large number of SCIAMACHY spectral measurement points inside the oxygen A-band. Interestingly, the SEVIRI/MSG - estimated average CTH for the SCIAMACHY pixel was 2.4 km, which gives 0.7 km overestimation. The SEVIRI cloud top temperatures were converted to the cloud top height using temperature profiles measured on ground at Lindenberg Observatory positioned close to the observation site. This points out again the problem with infrared cloud top height retrievals for low clouds. Similar estimates have been obtained using AATSR data. The problem with IR SEVIRI CTH measurements is mostly due to the underlying surface effects.

3. INTERCOMPARISON OF THE SACURA-RETRIEVED CLOUD OPTICAL THICKNESS WITH SATELLITE RETRIEVALS USING OTHER OPTICAL INSTRUMENTS

3.1. MODIS

SACURA retrieves not only cloud altitudes but also the cloud optical thickness, the cloud liquid water path(LWP), and the cloud effective radius (ER). However, only the cloud optical thickness and the cloud spherical albedo (SA) r are reported in the output of the operational SCIAMACHY processor. The value of SA for nonabsorbing channels is determined by the cloud transmittance t: $r = 1 - t$. The value of t is calculated as (Kokhanovsky et al., 2003):

$$t = \frac{1}{1.072 + 0.75\tau(1-g)}, \tag{1}$$

where g is the asymmetry parameter close to 0.85 for water clouds.

This section is aimed to studies of the accuracy of COT and also ER, LWP as retrieved by SACURA compar-

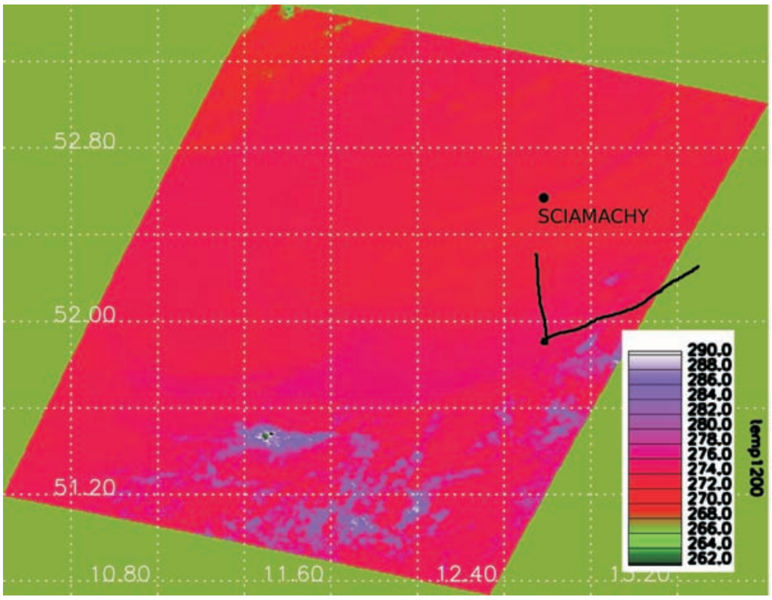

Figure 1. AATSR brightness temperature at 12 microns for the cloud field under study(orbit 11499 of ENVISAT, May 12, 2004, 10:00UTC). The flight path is shown by a line and the point gives the location of the center of the SCIAMACHY pixel.

ing the retrievals with comprehensively validated MODIS cloud products (Platnick et al., 2003). For this a completely cloud covered ground scene was used. The scene was centered over land at (16.49 E, 53.96 N). The same ENVISAT orbit as in the section above has been used. The MODIS retrievals were averaged with respect to a large 30*60km^2 SCIAMACHY ground scene. They gave 15.29 for COT, 9.9 microns for ER, 100.6 gm^{-2} for LWP and 2.5 km for CTH. This closely corresponds to the values retrieved using SCIAMACHY measurements (13.51 (COT), 10microns(ER), 87.3 gm^{-2}(LWP) , and 3.3 km(CTH)). The absolute values of the differences were 1.78 for COT, 0.1 micron for ER, 13.3 gm^{-2} for LWP, and 0.8 km for CTH. We expect that the differences will further decrease, when the SCIAMACHY Processor 6 is introduced. The smaller values of CTH as derived from MODIS can be due to the influence of ground emissivity for the studied case of low warm clouds.

3.2. MERIS and AATSR

We also have performed the comparison of the cloud optical thickness retrieved using MERIS and SCIAMACHY for the selected states of the orbit 11499 of ENVISAT (May 12, 2004; 10:00 UTC). This is shown for the region 52-54 N, 8-13 E in Fig.2. Two cloud algorithms were applied to MERIS data - SACURA and also the Free University of Berlin algorithm. We see that, as one might expect, SACURA MERIS retrievals are very close to those of SACURA/SCIAMACHY retrievals. The difference

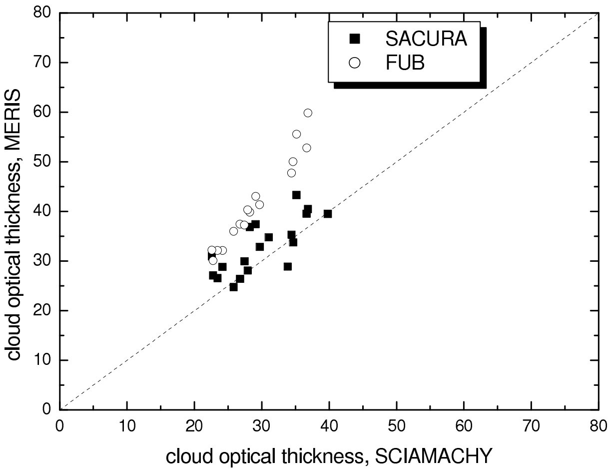

Figure 2. Intercomparison of the cloud optical thickness derived from SCIAMACHY and MERIS for the region 52-54 N, 8-13 E. SACURA was applied to both MERIS and SCIAMACHY data. The FUB LUT algorithm was applied only to MERIS data.

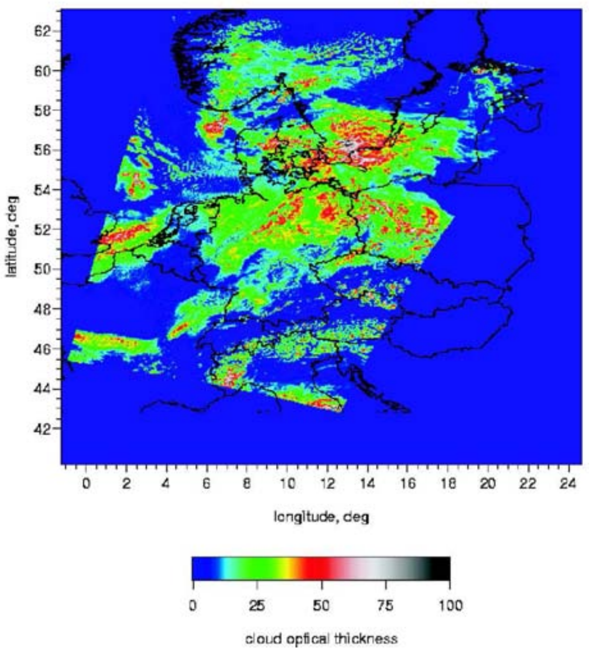

Figure 3. Cloud optical thickness map as derived from MERIS observations at the wavelength 443 nm using SACURA.

with FUB/MERIS retrievals is due the difference in a priori assumptions in both cloud MERIS algorithms. The FUB/MERIS algorithm produces values of AOT larger than those derived using SACURA retrievals. The spatial distribution of COT retrieved using SACURA/MERIS algorithm at 443 nm is shown in Fig.3. The AATSR official cloud products have not been realized so far. Therefore, we have used SACURA/AATSR algorithm to retrieve COT. The result of intercomparison is shown in Fig.4 for 16 SCIAMACHY pixels from the ENVISAT orbit 11499 depicted in Fig.5. It follows that cloud retrievals using SCIAMACHY and AATSR data produce comparable values of COT.

4. CONCLUSIONS

A comparison of the cloud top heights derived using oxygen A-band spectrometry with passive infrared and lidar measurements has been performed. The lidar measurements were taken as a reference. They have an accuracy of about 30 m taking into account the uncertainty of the flight height derived from the GPS. It was found that the standard SACURA SCIAMACHY algorithm overestimates CTH by 0.63 km. The error is reduced to just 0.18 km, if the vicarious calibration of SCIAMACHY is performed as explained above. Even smaller errors (0.04 km) are obtained, if the exact radiative transfer calculations are used in the retrieval process (and not the asymptotic theory as in the standard version of SACURA). Errors of CTH determined using 12 micron brightness temperatures were found to be larger as compared to oxygen A-band CTH measurements. The error of SACURA does not increase substantially for clouds situated at arbitrary height levels as can be concluded from the combination of this study, which is valid for low clouds, with earlier investigations (Kokhanovsky et al., 2004; Rozanov et al., 2004; 2006). In addition, we have compared COT as retrieved using SACURA with correspondent measurements performed by MISR, AATSR, and MODIS. All retrievals agree. Therefore, we conclude that SACURA performs well for extended cloud fields. It is planned to extend this study to broken cloud fields. However, in this case, the accuracy of SACURA is influenced in addition by the accuracy of the cloud fraction retrieval algorithm, the clear atmosphere model, and also the spectral reflectance database used.

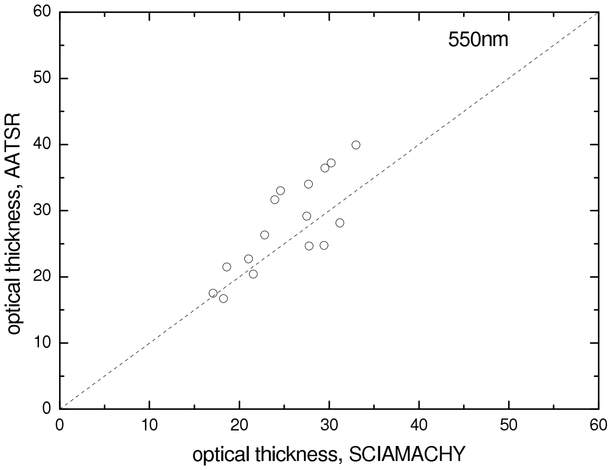

Figure 4. Intercomparison of the cloud optical thickness at 550 nm derived from SCIAMACHY and AATSR using SACURA for 16 SCIAMACHY pixels shown in Fig.5.

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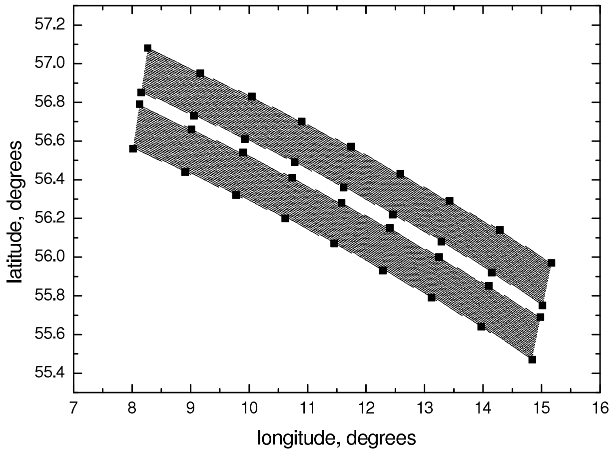

Figure 5. Position of selected pixels of SCIAMACHY (see 16 rectangular areas indicated by black boxes in corners). AATSR pixels are inside the SCIAMACHY large pixels (grey areas).

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